State of Maryland

BOARD OF NATURAL RESOURCES

MARYLAND
STREAM FLOW RECORDS

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MARYLAND STREAM FLOW RECORDS

The Maryland Legislature in 1933 declared it the policy of the State to control, as far as practicable, the appropriation or use of surface and underground waters of the State in accordance with the best interests of the people of Maryland. This law requires that a permit be obtained from the Water Resources Commission to use or appropriate any waters of the State, surface or underground, except for domestic purposes. Since 1941, the administration of this act has been delegated to the Department of Geology, Mines and Water Resources. To administer it intelligently and equitably, the Department needs to know what the surface and underground water resources of the State are. Herein is an analysis of the extent to which this information is available concerning the surface water resources.

The Geological and Economic Survey, established in 1896, recognized the need of inventorying the surface and underground waters of the State long before the passage of the 1933 Act. During its first year it began financial support of stream gaging stations to measure the surface water resources, and in 1918 it published a report on "The Surface and Underground Water Resources of Maryland." Little further progress had been made in investigating the underground water resources of Maryland until the present intensive study of the Baltimore regional area was initiated late in 1942 to meet an increasingly acute shortage and increasing contamination of the underground waters of this important industrial region.

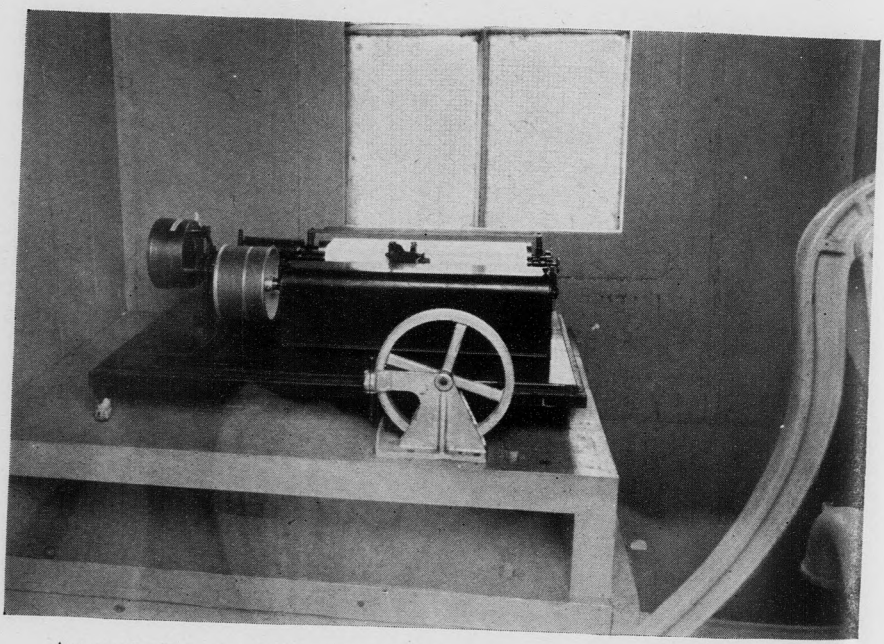
More progress was made in inventorying the surface waters by a progressive increase in the number of stream gaging stations. The records of the stream gaging stations are published annually in the Water Supply papers of the United States Geological Survey, but it requires tedious and time consuming search to make them available for use. A part of these records was summarized in 1940 in a report published by the Water Resources Commission and the State Planning Commission entitled "Flow Data and Draft Storage Curves for Major Streams 1929-1937." The Department of Geology, Mines and Water Resources has published all of these records in a "Summary of Records of Surface Waters of Maryland and the Potomac River Basin 1892-1943."* This Bulletin contains the records of all of these stations, aggregating a total of 990 years. It gives by months the maximum, minimum

* Bulletin No. 1, Department of Geology, Mines & Water Resources. The Johns Hopkins University, Baltimore 18. Available for distribution.

and mean daily discharge in second feet, the monthly runoff in inches and the average daily discharge in million gallons per square mile of drainage area. It also gives by years the mean discharge in second feet and per square mile of drainage area, the run-off in inches, and the average discharge in million gallons per day per square mile of drainage area.

THE INSTALLATION OF MARYLAND GAGING STATIONS

Progress in the installation of stream gaging stations in Maryland was slow prior to 1920 despite the fact that the first station was installed as far back as 1892. Moreover, of a total of 70 stations that have been installed, only 47 are now in operation. Only two of the 20 stations installed prior to 1920 are still in operation. The stations established since 1920 have fared better, and 45 of these 50 are still in operation. The value and usefulness of stream gaging records increases with the number of years over which they extend, so that the records of the newer stations are not nearly as valuable as would have been continued records of the older stations.



Automatic Recorder in Gage House at Sharpsburg on Antietam Creek. This instrument records continuously the level of the water.

The number of stations installed in each decade and the number still in operation are:

SUMMARY OF STREAM GAGING INSTALLATIONS

Decade	*Installed*	*Still Operating*
1892 - 1899	9	1
1900 - 1909	7	0
1910 - 1919	4	1
1920 - 1929	18	16
1930 - 1939	21	17
1940 - 1944	11	12*
Total	70	47

The two existing stations installed prior to 1920 are the Potomac River station at Point of Rocks, which was installed in 1895 and has one of the longest continuous records of stream flow in the United States, and the station near Frederick on the Monocacy River which was installed in 1896. The latter station was moved in 1930 from the Ceresville bridge to the Jug bridge. Only seven other Maryland streams have continuous records dating back more than fifteen years. They are:

STREAMS WITH RECORDS OF MORE THAN 15 YEARS

Stream	*Installation Date*
Patuxent River	1913
Deer Creek	1925
Seneca Creek	1925
Little Gunpowder Falls	1926
North Branch Patapsco River	1927
Antietam Creek	1928
Conococheague Creek	1928

The Seneca Creek station was moved in 1931 from Gaithersburg to Dawsonville.

MAINTENANCE OF GAGING STATIONS

The stream gaging stations are operated by the United States Geological Survey, and are financed either entirely by Federal funds or, in part, on a cooperative basis jointly by Federal funds and Maryland funds. The Maryland funds are provided in part by the State and in part by municipalities and other divisions of the State and by industries within the State that are dependent on the streams on which the stations are located. That is, the need for stream flow records is in excess of the provision that the State has made for them and has had to be met by intrastate contributions.

The 47 active stations are financed as follows:

*Measurements were resumed in 1940 at an earlier discontinued station.

OPERATING COST OF GAGING STATIONS

State of Maryland	$5,000.00	annually
Intra-State contributors	5,100.00	"
Federal Agencies	15,115.00	"
Total	$25,215.00	"

The Federal government not only matches the $10,100.00 of Maryland money, but supplies in addition $5,015.00 annually for wholly Federal supported stations. The latter are located in the Potomac River basin and serve, also, as inter-state stations. The State of Maryland is paying less than twenty cents for every dollar's worth of stream flow information it is receiving.

An important need is the continued financing of the existing stations over a sufficient number of years to make the records reasonably complete and of maximum value and use. In the event that the intra-State agencies should withdraw their financial support from any of the stations, provision should be at hand to continue those stations with State funds.

Adequate inventorying of the surface waters of the State requires the installation of additional stations in order to anticipate foreseeable near future needs and the less evident needs of the distant future, and to secure a more complete and uniform coverage of the streams of the State. The Department of Geology, Mines and Water Resources, in consultation with the Maryland Department of Health and the United States Geological Survey, has drawn up a list of 19 stations that are needed for community water supplies, sewage and other waste disposal, and for more complete and uniform coverage of the streams of the State.

Intra-state agencies and industries will, in future development, need long time records of the flow of streams which have not been provided with gaging stations. They do not usually plan far enough in the future or assume the cost of such long time planning to assure the availability of the flow records when they are needed. The lead in assuring such information must be assumed by the State in conformity with its declared policy to utilize these waters in accordance with the best interests of the people of Maryland. This policy can be carried out effectively and intelligently only to the extent to which the State has determined the volume of the waters involved.

The coverage of the State by gaging stations is very ununiform both areally and by drainage basins. This unequal distribution is apparent on the map showing the locations of existing and abandoned gaging stations that accompanies Bulletin 1. Nearly all of these stations are in the Appalachian and Piedmont provinces of Maryland. That is, nearly all of the stations lie north and west of a line through Washington, Baltimore, and Havre de Grace. There has been very little gaging of the streams of the Coastal Plain province,

that is, the streams of the Tidewater counties. The Eastern Shore has but one station, that located on the East Branch of the Wicomico River, near Salisbury. Southern Maryland has only three stations, one each on the North River and Bacon Ridge Branch, both tributaries of the South River, and one on Saw Mill Creek, at Glen Burnie. One of these four Coastal Plain stations is supported by State funds and the other three by intrastate agencies. Proper areal coverage, specific immediate needs, and foreseeable future needs require the installation of additional stations in Southern Maryland and on the Eastern Shore. These stations would have to be provided for at present by intrastate agencies that are willing to contribute the operating costs. The records of such stations and of existing stations financed by intra-state agencies are needed by the State to carry out the control it has assumed over the utilization and appropriation of its surface waters.

AVERAGE FLOW RATE OF MARYLAND STREAMS

Unless a gaging station has been in operation for a long time, its records are not a reliable guide to the maximum probable flood flow, the minimum probable drought flow, or even of the average annual mean flow. Only nine Maryland streams are covered by continuous records of more than fifteen years' duration. Since the drainage areas above the stations on these nine streams vary greatly, a comparison of their rate of flow must be based on the average daily flow in million gallons per square mile of drainage area. This average rate of flow during the fifteen years immediately preceding October 1, 1943 was:

FLOW RATES OF MARYLAND STREAMS WITH LONGEST RECORDS

Stream	*Million Gallons Daily per Square Miles Drainage*	*Square Miles of Drainage Area Above Station*
Deer Creek	0.799	94.4
Little Gunpowder Falls	0.789	36.1
Conococheague Creek	0.737	494.0
Monocacy River	0.723	817.0
North Branch Patapsco River	0.664	91.0
Potomac River	0.605	9651.0
Antietam Creek	0.596	281.0
Patuxent River	0.592+	127.0
Seneca Creek	0.564	101.0

That it is hazardous to assume that these average flow rates during 15 years will be maintained over a longer period of time is demonstrated by an analysis of the flow records of the Monocacy River over a period of 48 years.

THE MONOCACY RIVER FLOW

Yearly discharge records on the Monocacy River are available beginning with 1897. A comparison of the discharge records of the first years of the gaging station with the records of the last years shows a marked decrease in the flow of this river. The average discharge during the years 1897 to 1903 was 1.135 million gallons per square mile, whereas the average discharge during the years 1937 to 1943 was only 0.784, or only 69% as much. In other words during the earlier period the river carried nearly one and a half times the volume of water it did during the later period. If this represents a progressive and continuing decrease in the flow of this stream and if a similar change is taking place in other streams of the State, then the surface water resources of Maryland are undergoing a seriously rapid decrease. It would suggest that pronounced changes are taking place in the drainage basins of our streams.

The most apparent changes for which man is responsible are in the vegetable and soil covers. The former is largely deforestation, and the latter is soil erosion resulting from deforestation and improper farming. These factors are progressive and continuing in their effect. If they caused a notable progressive decrease in precipitation, they would have caused a marked decrease in stream flow. If they have only changed the ratio between runoff and ground water storage they could not have caused such a large decrease in flow. If they increased the runoff, they merely increased the flood flows and decreased the drought flows. If they increased the underground storage, they may have decreased the flood flows and increased the drought flows. That is, they either increased the range of the ups and downs of the stream flow curve or they smoothed that curve by decreasing the range of the ups and downs. The Weather Bureau records show that the amount of water falling in the drainage basin remained the same, so the average discharge should have remained the same. However, if the removal of vegetation and soil cover of the drainage basins greatly increased evaporation, a decrease in stream flow would have resulted. It would seem, therefore, that the decrease in the flow of the Monocacy River must have been caused by a great increase in the rate of evaporation in its drainage basin.

There are two Weather Bureau stations in the Monocacy River basin, one at Frederick and one at Emmittsburg. The rainfall records of these stations show large variations in the annual precipitation during the period covered by the stream flow records. The annual precipitation at the Frederick station ranged between 19.84 inches and 51.98 inches and average 41.22 inches. At the Emmittsburg station the range was 27.69 inches to 65.29 inches and the average was 44.80 inches. These great fluctuations in amount of rainfall were reflected in corresponding fluctuations in the flow of the Monocacy

River. However, the rainfall records show no progressive change with time, even if one considers the average over such short intervals as five years. The variations in five year periods expressed in terms of percentage of the average for the whole period are:

RAINFALL IN MONOCACY RIVER VALLEY

Period	*Frederick*	*Emmittsburg*	*Average*
1899 - 1903	106	100	103
1904 - 1908	99	101	100
1909 - 1913	92	98	95
1914 - 1918	108	103	105
1919 - 1923	96	96	96
1924 - 1928	106	100	103
1929 - 1933	95	99	97
1934 - 1938	105	101	103
1939 - 1943	94	102	98

It is obvious that no change has taken place in the amount of precipitation in the Monocacy River basin. The decrease in the flow of the Monocacy River can not be accounted for, consequently, by a change in the climate.

The high discharge records of the early years of the Monocacy River do not decrease progressively to the lower discharge records of the recent years, but decrease rather abruptly about 1909, and then remain nearly uniform after 1909. The average discharge of the river during the 35 years from 1909 to 1943 was 0.776 million gallons per day per square mile of drainage area. The average discharge during intervals expressed in percentage of the average during these 35 years was:

VARIATIONS IN FLOW OF MONOCACY RIVER

Period	*Average Discharge*
1897 - 1901	115
1902 - 1903	224
1904 - 1908	144
1909 - 1913	99
1914 - 1918	118
1919 - 1923	85
1924 - 1928	108
1929 - 1933	84
1934 - 1938	98
1939 - 1943	98

The span of the Monocacy River stream flow records began with an interval of four years during which the flow was 15% greater than the average of the last 35 years. A two year interval followed in which the discharge went up to 224% and the rainfall increased to 116%. During the next five years, the discharge averaged 144% but rainfall dropped to 100%. In 1909, the discharge decreased to 90%, reflecting a decrease in the rainfall of that year

to 81%. Variations in flow during the next 35 years are proportional to variations in the rainfall and show no progressive decrease.

The story of the variations in the discharge records of the Monocacy River in percentage of the average discharge during the last 35 years is that during the first record year the discharge was 97%. A period of ten years followed during which the discharge was high and reached a peak of 271% in 1903. The average discharge during these 10 years was 152%. However, in one of these years, the discharge dropped to 88% and in another to 92%. During the first 15 years of the last 35 years the discharge averaged 101% and rainfall averaged 99%. During the last 15 years the discharge averaged 93%, and rainfall averaged 99%. There has consequently been a decrease in the flow of the Monocacy River of over 50% during the period covered by the flow records, but nearly all of that decrease occurred abruptly at about 1909. Since 1909 the river has maintained a reasonably uniform flow.

The precipitation that falls on a drainage basin is carried away as direct run-off, deep seepage into ground water, and loss by evaporation. The last named loss consists of the water directly evaporated and that lost through transpiration by the vegetation. The relations between these three modes of removal of the precipitation are controlled by a number of factors such as precipitation intensity and distribution, type of vegetation, topography, soil, temperature, wind, sunshine, and humidity. Explanation of variations in the flow of a stream is a complex problem that requires a vast array of data about a large number of variable factors. Some of these factors are subject to great irregular variations, such as precipitation intensity and distribution, temperature, wind, sunshine and humidity. Other factors are subject to only slow progressive change such as type of vegetation, topography, and soil. The abrupt change in the flow of the Monocacy River can be accounted for only by the factors subject to great or rapid variation.

During the last 35 years, there has been no abrupt change in precipitation or in stream flow. In averaging stream flow over periods of 5 years, there should be little variation in the sum of direct run-off and run-off discharged from deep seepage, so that we need consider only the relation between total run-off and total loss to precipitation. These three quantities expressed in inches per year over five year intervals are:

RELATION BETWEEN RAINFALL, RUN-OFF AND LOSS

Period	*Precipitation*	*Run-off*	*Loss*
1899 - 1903	44.27	26.16	18.11
1904 - 1908	42.89	23.57	19.32
1909 - 1913	40.89	16.17	24.72
1914 - 1918	45.25	19.21	26.04
1919 - 1923	41.31	14.29	27.02
1924 - 1928	44.22	19.32	24.90

1929 - 1933	41.82	13.60	28.22
1934 - 1938	44.22	15.98	28.24
1939 - 1943	42.23	16.01	26.22
Last 35 years	42.85	16.39	26.48

During the last 35 years 40% of the precipitation in the Monocacy drainage basin has been carried off by the river and 60% has been lost to the river. In the preceding 10 years, the relations were almost reversed, 57% being carried off by the river and 43% being lost to the river.

Which of these two conditions is to be taken as the normal condition for the Monocacy drainage basin and which as the abnormal one? The 35 year period would more likely be the stable condition and the preceding 10 year period the unstable one. That the years preceding 1909 were abnormal years is shown by a further breakdown of the data for those years. These

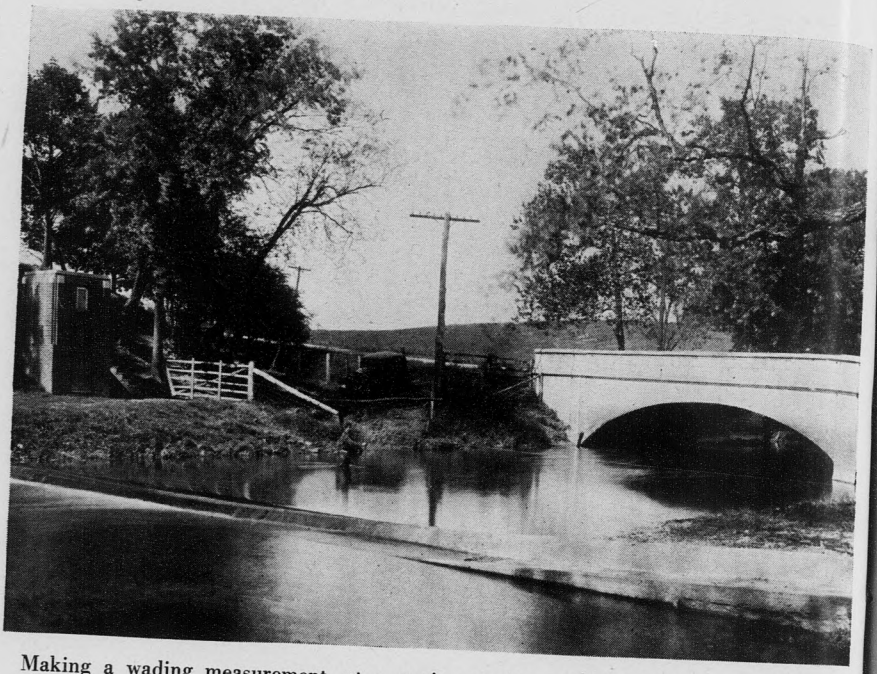
RELATION BETWEEN RAINFALL, RUN-OFF AND LOSS, 1898-1908

Period	*Precipitation*	*Run-off*	*Loss*
1898 - 1901	40.22	19.52	20.70
1902 - 1903	49.62	36.55	13.07
1904 - 1908	42.89	23.57	19.32
Average next 35 years	42.85	16.39	26.48

eleven years were marked by two years of excessive rainfall and by high run-off and low loss. The problem is to explain the marked increase in loss about 1909.

The decrease in loss in 1902-1903 as compared with the years immediately preceding and immediately following is understandable because of the great increase in precipitation during 1902-1903. These must have been years of less than normal sunshine and higher than normal humidity, and hence of less than normal loss by evaporation. The same explanation cannot apply to the equally marked increase in loss that occurred about 1909 and which remained fairly uniform for the next 35 years. One is almost compelled to seek a catastrophic explanation for this change.

The Monocacy River flows in a limestone valley. Limestones are more readily soluble than rocks, and limestone areas are characterized by underground caves and solution channels connected with the surface by "sink holes" into which surface waters empty. Some limestone areas have such an extensive system of underground water courses that all surface waters empty into "sink holes," and the areas are devoid of surface streams. There is the possibility, then, that about 1909, the Monocacy River suddenly discharged part of its flow into some subterraneum water course. Two gaging stations on the Monocacy River further upstream permit a partial check on this hypothesis. One of the large tributaries of the Monocacy River is Linganore Creek.



Making a wading measurement, at a gaging station equipped with recording gage (brick wall) and artificial control.

A gaging station has been operated near the mouth of Linganore Creek since 1934. The average flow at this station has been 0.662 million gallons per day per square mile. The average flow at the Jug Bridge station on the Monocacy River during the same period has been 0.779 million gallons. The records do not indicate a large diversion to underground water courses of Monocacy River water between these two stations. In 1942, a gaging station was established much farther upstream on the Monocacy River at Bridgeport. The average flow in million gallons per day per square mile at the three stations from May, 1942, to September, 1943, was:

COMPARISON OF FLOWS AT MONOCACY RIVER STATIONS

Station	*Flow*
Bridgeport	1.069
Linganore	0.821
Jug Bridge	0.905

The records no not indicate a large diversion to underground water courses of Monocacy River water between these stations. These data, however, do not rule out the possibility of such diversion on the Monocacy River above the Bridgeport station or on other large tributaries of the Monocacy River

between Bridgeport and Jug Bridge for which there are no stream flow measurements. However, it would require an unreasonably large number of gaging stations to prove such a diversion of the Monocacy River water.

Unfortunately, the Monocacy River station was established just at the beginning of the decade of large flow. In the first year of the station, the flow was the same as the average during the last 35 years. Was this the end of a period of normal flow followed by a decade of abnormally large flow which was succeeded again by 35 years of normal flow? In the tabulation of the flow of the nine streams for which records are available during the last 15 years, the Monocacy River rate of discharge ranks fourth and there is little difference in the four highest streams. The present flow of the Monocacy River is, consequently, equal to that of the best of Maryland streams. Hence, the much larger flow of the decade preceding 1909 is more logically regarded as the abnormal flow, and one should seek an explanation for this abnormally large flow. We know nothing about the flow of the Monocacy River during the years preceding this decade because the stream flow records do not begin until 1897.

Another approach to the significance of the behavior of the Monocacy River is to compare its flow with the flow of other Maryland rivers. Only one other river, the Potomac, has records that extend as far back as the records of the Monocacy River. It is the only river available for such a comparison. The Point of Rocks gaging station was established in 1895. The average discharge of the Potomac River during intervals expressed in percentage of the average discharge during the 35 year period from 1909 to 1943 and the average discharge of the Monocacy River during the same intervals are:

COMPARISON OF VARIATIONS IN FLOW OF POTOMAC AND MONOCACY RIVERS

	Potomac	*Monocacy*
1897 - 1901	118	115
1902 - 1903	161	224
1904 - 1908	112	144
1909 - 1913	89	99
1914 - 1918	106	118
1919 - 1923	87	85
1924 - 1928	116	108
1929 - 1933	88	84
1934 - 1938	112	98
1939 - 1943	102	98

This comparison shows reasonably close correspondence between the two rivers in five year intervals, though they drain entirely separate and distant

areas, especially when one considers the variations in rainfall in two such nearby Weather Bureau stations as Frederick and Emmittsburg in the same drainage basin. It shows that the decade preceding 1909 was marked by more than normal discharge in the Potomac River though by no means as much above normal as was the Monocacy River discharge during that decade. The two peak years, 1902-1903, on the Monocacy were also peak years on the Potomac. The average flow of the Potomac River during the first 15 years of the last 35 years was 94% and for the last 15 years was 101%, exactly the reverse of the flow of the Monocacy River. It would appear that whatever may have been the cause of the abnormal flow of the Monocacy River during the decade preceding 1909, affected the Potomac River also in the same way but not nearly as much. The comparison of the flow histories of the two rivers since 1909 gives no indication of a progressive change in the flow of the rivers of Maryland during the last 35 years.

FLOW INCREMENTS ALONG THE COURSE OF A RIVER

An interesting question regarding the flow of a river is the rate at which water is discharged into it along its water shed. This problem requires stream flow records at a number of places along its course. The only Maryland river provided with such a distribution of gaging stations is the Potomac River. The average flow of the Potomac River in million gallons per day per square mile during the five years 1939-1942 and the area of the drainage basin in square miles above the station at Potomac River stations are:

CHANGES IN FLOW ALONG THE POTOMAC RIVER

Station	*Discharge*	*Drainage Area*
Bloomington	1.079	287
Cumberland	0.823	875
Hancock	0.556	4073
Shepherdstown	0.558	5936
Point of Rocks	0.547	9651
Washington	0.540	11560

For the Potomac River at least, the contribution to the flow of the river per square mile of watershed is more than twice as great near the headwaters than it is in the lower course of the river. The contribution falls off rapidly in the upper course of the river and remains quite uniform in the lower course of the river. There are no records of other Maryland rivers to compare with the Potomac River records. It is likely that the other Maryland streams show a similar behavior pattern with quantitative modifications depending on topographic differencies along the courses of the stream.

NECESSITY FOR LONG TERM FLOW RECORDS

The widespread recognition of the usefulness and value of stream flow records is evidenced, in the first place, by the fact that over $25,000.00 is being expended annually in measuring the flow of Maryland streams and, in the second place, by the fact that these funds are provided by such diversified interests as the Federal government, the State of Maryland, municipalities, other divisions of the State, and industries within the State. These records are necessary in planning all projects that utilize or are dependent on the flow of a stream. Projects such as water power development, water storage, flood control, water supply, industrial uses, sewage and other waste disposal, bridges and irrigation are dependent on the volume of flow and on the variations in that volume.

Not so definitely recognized is the fact that these records are reliable and of maximum value only if they extend over a long period of time. It is only then that one can be reasonably confident the records represent truly the average flow, the maximum probable flood flow and the minimum probable drought flow. When these rates are established with reasonable certainty and reliability by records extending over a sufficiently long period of years, less latitude is necessary in the plans for such projects to provide for departures from the flows shown by the records. When these records extend over a relatively small number of years, one can not be sure that their mean represents the true average flow of the river or that the river may not be subject to much greater floods or much more severe drought flows than disclosed by the records. Plans for construction projects on the river must then provide for the possibility of much greater departures from the recorded flows, which involves higher construction costs. It is important, therefore, that adequate coverage of the streams of the State with gaging stations be anticipated a sufficiently long time in advance of the need for the records to assure the maximum usefulness and dependability. This assurance can be had only if the State itself has been alive to its responsibility.

The story of the discharge of the Monocacy River over a period of 48 years illustrates admirably the necessity of accumulating flow records over a long period before they can be relied upon in planning projects dependent on the volume of flow. Any such projects that might have been planned on the flow records of the first 12 years of gaging would have been predicated on one and a half times the volume of the flow realized during the next 35 years. Any such projects based only on the records of the last 35 years would be subject to the consequences of a ten year period of a flow one and a half times as great as had been anticipated. In view of the fact that only nine Maryland records extend over a period of more than 15 years, it is evident that our knowledge of the behavior of Maryland streams is extremely incom-

plete and fragmentary and that great latitude must be provided in projects involving the volume of flow for wide departures from the recorded maxima, minima, and means. It is likewise evident that the continued maintenance of the existing gaging stations is a real public need.

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